# DEVELOPMENTS IN CONTOURING TECHNIQUES

by

P.R. Cockrell

ECMWF SEMINAR ON GRAPHICAL APPLICATIONS IN METEOROLOGY

# A new approach to the production of contour charts.

by
P.R.COCKRELL
Systems Development Branch, Meteorological Office, UK

Abstract

An attempt to find a contouring algorithm suited to vector processors, such as CRAY-1 or Cyber 205, has led to a new technique apparently able to provide a general solution covering a large proportion of Met. Office applications. In addition some normally expensive (ie CPU intensive) operations, notably shading or colouring between contours and selective treatment of oddly shaped regions (masking), are natural extensions of the method requiring little extra CPU time.

## 1. Introduction.

The Meteorological Office has a large operational observing and forecasting commitment backed up by an extensive research and development program. The total operation is heavily dependent upon a powerful central computer installation (COSMOS) for the assimilation and archiving of weather data and the running of atmospheric models of various kinds as well as a large amount of general scientific computing. The installation comprises two IBM main-frame machines (360/195 and 370/158) and the recently acquired CDC Cyber 205 vector processor capable of up to 400 million floating point operations per second (MFLOPS). Graphical displays are produced on pen-plotters, 35mm microfilm, lineprinters and CRT interactive terminals.

Additionally a network of Outstation Automation Systems (OASYS), linked to Bracknell, is now being installed incorporating twin DEC PDP 11/60 mini-computers driving electrostatic printer/plotters, drum plotters and, in the near future, interactive colour terminals with raster and vector capability.

Operational contour (iso-line) charts have been produced in large quantities for many years on COSMOS by a cubic-spline fitting program employing a "search-and-follow" algorithm. It is now necessary to extend the contouring work to the mini-computers and to transfer some of the operational chart production to the Cyber 205.

The existing operational program is satisfactory for most general chart-work in the forecast office but is limited to "well behaved" data (eg. Fig 1.). More difficult grids (eg Fig 2.from a cumulus model) are handled badly. Several other programs exist which have been prepared for, and are limited to, special purposes.

A program employing the new algorithm is being developed in standard FORTRAN to allow portability between computers and is being evaluated by both the research and services branches within the Office.

This paper is intended to emphasise the generality of the method rather than describe the existing computer program but unless otherwise stated the features described have at least been demonstrated as feasible.

Contouring algorithm (Cockrell)

2. Overview of the basic approach.

A series of closely spaced parallel lines (raster lines) are considered on a rectangular grid as shown in Diagram 1. The contour intersections on these lines are found by a vectorisable algorithm and then linked together on adjacent lines by a fast scalar method. Although fundamentally a raster-scan approach, results can be plotted in either raster- or vector-mode.

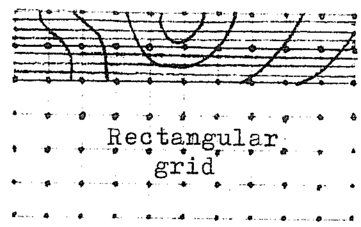



Diagram 1.

3. Locating the contour intersections on a raster line. (Diagram 2).

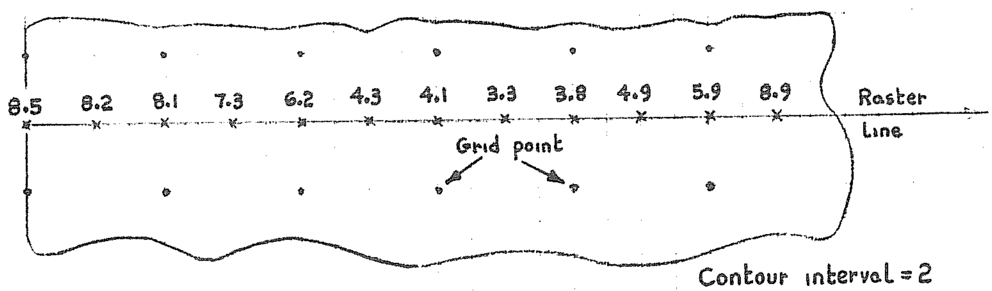



Diagram 2

| | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| (i) | 8.5 | 8.2 | 8.1 | 7.3 | 6.2 | 4.3 | 4.1 | 3.3 | 3.8 | 4.9 | 5.9 | 8.9 | |
| (ii) | 4 | 4 | 4 | 3 | 3 | 2 | 2 | 1 | 1 | 2 | 2 | 4 | |
| (iii) | 0 | 0 | -1 | 0 | -1 | 0 | -1 | 0 | 1 | 0 | 2 | | |

(i) Bicubic interpolation is used to obtain values at equal intervals along the raster line. The spacing of these points is to be such that linear interpolation between them is tolerable. This operation is the major consumer of CPU time in the process and a divided difference scheme is used to give a fast and numerically sound program kernel suited to vector processing.

(ii) The values found in (i) are divided by the contour interval and then truncated to integers.

(iii) First differences are taken of the results of stage (ii)

The non-zero results of (iii) then mark the contour intersections. These "markers" are used to gather the data required for inverse linear interpolation which in turn yields the contour values and their precise locations on the raster line.

Note that:-

- absolute values at (iii) indicate the number of contours in the corresponding interval, and
- the sign of a value at (iii) indicates which of the two possible values at (ii) can be taken as the (coded) contour value.

Operations (i) to (iii) above can be coded efficiently for both vector and scalar processors.

If the intersections obtained at this stage are simply plotted as dots on straight lines a picture such as Fig 3 is obtained. This is clearly promising but is unsatisfactory when contours lie nearly parallel to the raster lines. A very high density of raster-scans produces an (expensive) improvement but is not a cure.

Some important advantages apparent at this stage are:

- Smoothly changing surface gradients (cf Fig 2).
- Contours do not (in fact cannot) intersect and the well known "saddle-point" problem does not arise.
- The contour pattern can be arbitrarily complicated ie. there are no special cases to search for.

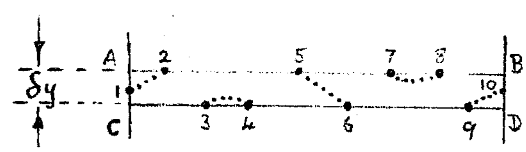
Further progress depends upon there being a reliable and efficient algorithm for linking the points on one raster to the correct points on its neighbour.

4. Linking contours between raster lines.

Consider the narrow rectangle ABCD in Diagram 4 bounded by the chart edges AC and BD and raster-lines AB and CD.

An arbitrary number of contours intersect the boundaries of ABCD.

Assume that all contours are separated in the y-direction by an amount greater than $\delta y$ in the diagram. (The raster spacing ($\delta y$) can be chosen so that this is the case.) Number the intersections from left to right as shown.




Then the required linkage will always be 1-2, 3-4, 5-6, ...etc.

Proof:-

- A contour "enters" the strip at intersection No.1.
- One and only one contour must exist between intersections 1 and 2 (on the given assumption).
- Intersection No. 2 is therefore the exit point of the contour entering at 1.
- No contour exists between 2 and 3 but one must enter at 3 and exit at 4.
- Similar entries and exits then occur alternately until the last intersection on the right which can only be an "exit".

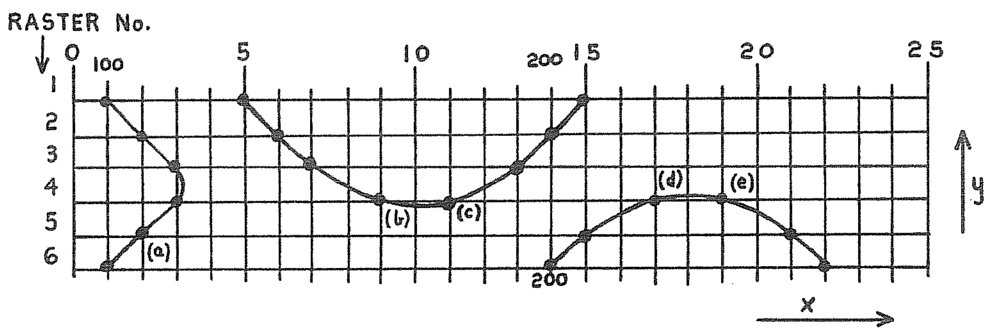
Figure 4 demonstrates that the method can be relied upon to link a complex pattern of contours correctly.

Note that:-

- Contour values are not needed in the proof but they do provide a useful, if inconclusive, check on the correct linkage in the computer program.
- As with the contour location process the linking procedure cannot produce intersecting contours.
- The assumption used in this proof regarding contour density is not essential but the present computer program makes use of it to simplify the code. A more efficient program would result from removing the assumption.

5. Computer representation of the contours.

For convenience in plotting and labelling operations the rasters are linked together in bands and the resulting contour segments are represented in a table as shown in Diagram 4.




| | (a) | (b) | (c) | (d) | (e) |
|---|---|---|---|---|---|
| 1 | 1 | 5 | 15 | | |
| 2 | 2 | 6 | 14 | | |
| 3 | 3 | 7 | 13 | -19 | |
| 4 | 3 | 9 | 11 | 17 | 19 |
| 5 | 2 | -11 | | 15 | 21 |
| 6 | 1 | | | 14 | 22 |
| CONTOUR VALUES | 100 | 200 | 200 | 200 | 200 |

Diagram 4

Each column of figures in this table represents the x-coordinates of a contour where it intersects the raster-lines. Each row represents a raster-line and y-coordinates are given by the appropriately scaled row number.

Contour values are stored in the separate row vector.

The data may be accessed in various ways for different operations in the plotting process.

- Vector plotting on micro-film ("Beam-off" time is unimportant)

  All points in a given column are plotted before moving to the next column.

- Pure raster plotting (including facsimile or lineprinter devices)

  Set raster elements to join the first two x-coordinates in each column eg 1-2, 5-6, and 15-14 Repeat for the next raster joining rows 2 and 3 of the table and so on until all data have been plotted.

- Electro-static devices with hardware vector-to-raster conversion.

  The banded arrangement of vectors illustrated in diagram 4. is the preferred format for this type of device and plotting is performed in the same order as for micro-film.

- Pen-plotting ("pen-up" time is important).

  A special routine is necessary to arrange the short segments from several bands into a sensible order for this type of plotting.

6. Shading regions between selected contours.

The positions of the contour intersections and the rounded-down inter-contour values are found during the location process so that lines (or rows of symbols) of different intensities or colours may be drawn along the raster-lines between selected contour values allowing accurate shading for little extra CPU time. A further advantage is that shading may be performed concurrently with drawing contours. Figs 5 and 6 provide an example of the use of shading in emphasising the main features of charts.

7. Masking.

In some applications it is necessary to plot contours only in selected areas of charts eg oceanographic data analysis. the raster-scan approach is particularly well suited to this problem.

The mask itself is represented as a series of narrow strips on which the edges (eg. coastlines) are recorded as displacements from the left hand edge of the chart. These narrow strips may then be readily accessed when plotting or shading in the corresponding strips used in the contouring process.

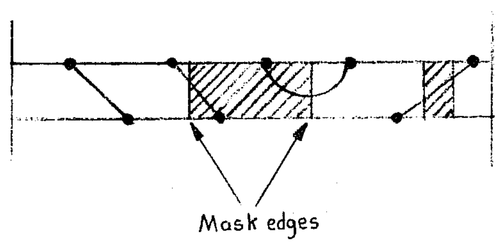



Diagram 5

The decision as to whether a given vector is interupted or obscured by the mask is a very quick operation. Diagram 5 illustrates the basic masking operation and Fig 7. demonstrates the effect.

Once prepared the mask may be used in the opposite sense, perhaps to plot land data as in Fig 8. Alternatively the mask may be used in a multi-pass process to treat selected areas in different ways as in Figs 9 and 10.

8. Smoothing.

No attempt is made in the present program to smooth the data before or after contouring. This results in the drawing of "cusps" when contours are not smoothly represented by piecewise cubic equations. The effect can be clearly seen in Fig 4.

Research workers in general find this acceptable while forecasters would prefer a smoother appearance on certain of their operational charts. Experiments with smoothing techniques are in progress and an improvement in this respect is expected in the near future.

9. Summary of the present state of development.

A program employing the new algorithm has reached the point where it can reliably perform contouring, shading, and labelling on a wide variety of chart types. The program has been tested extensively on the IBM 360/195 and 370/158, and limited testing has begun on the Cyber 205 vector processor and on DEC PDP11/60 mini-computers.

It has been demonstrated that "masking" operations and device independence are "natural" to the method. Other features such as drawing contours at unequal intervals and the marking of maxima and minima do not pose any particular problems. Substantial use of the program is already being made in research work but it does not yet have operational status.

10. Acknowledgements.

The author wishes to thank Dr W.A.McIlveen for asking the original question "Is there a contouring algorithm suited to vector processors such as the CRAY-1 or Cyber 205" and for much help and encouragement with the work itself. Thanks are due also to Mr. C.Russell who has helped with the implementation work throughout.

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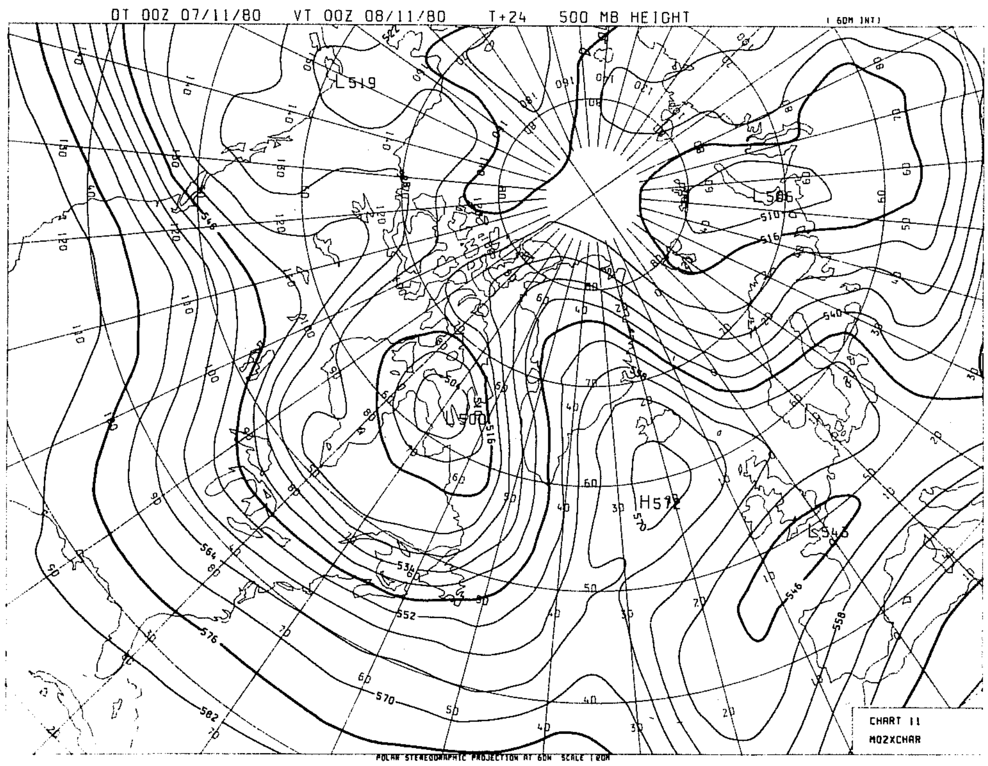
DT 00Z 07/11/80 VT 00Z 08/11/80 T+24 500 MB HEIGHT
CHART 11
MO2XCHAR

Fig. 1

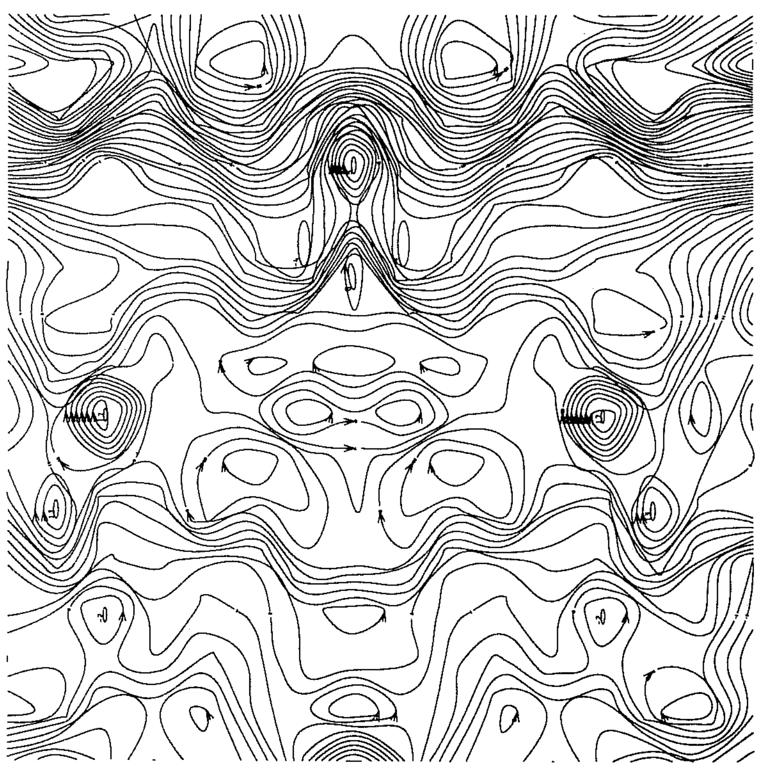

Fig. 2

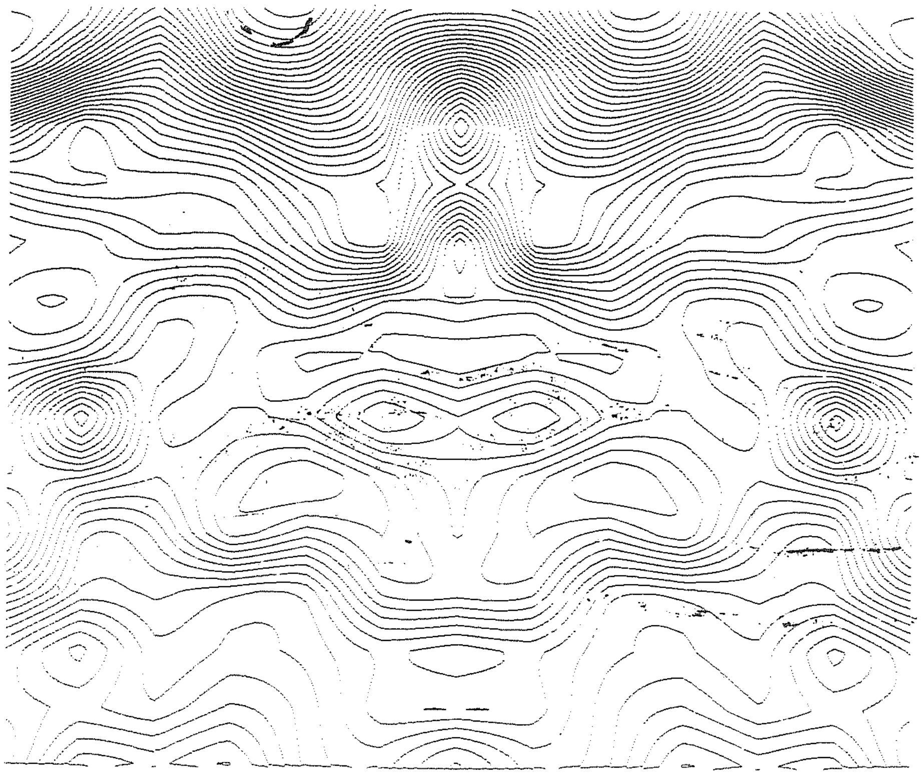

Fig. 3

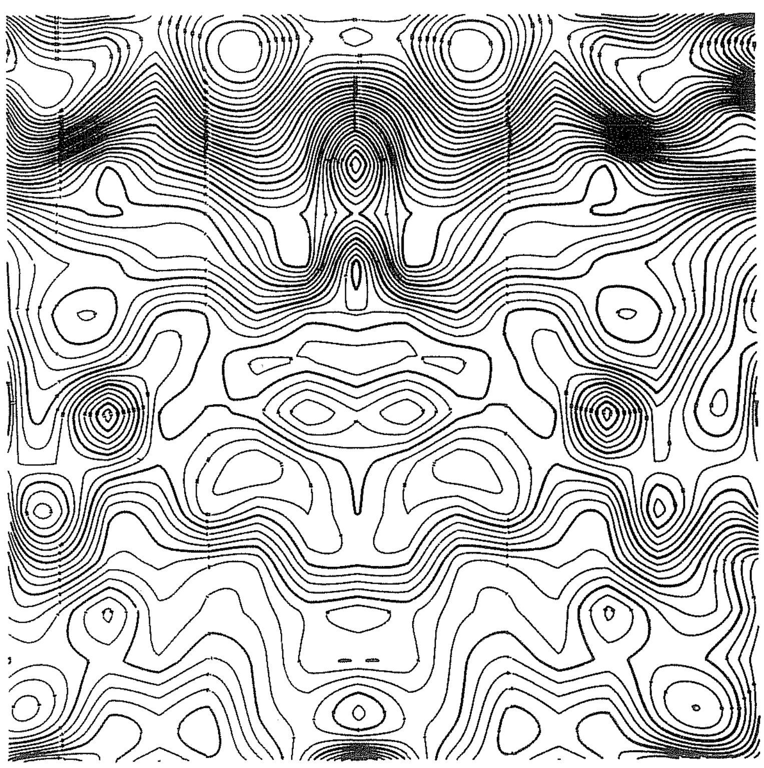

Fig. 4

DT 12Z 15/10/79 VT 12Z 16/10/79 T+24 950 MB REL. HUMIDITY (20% INT) UPDATE

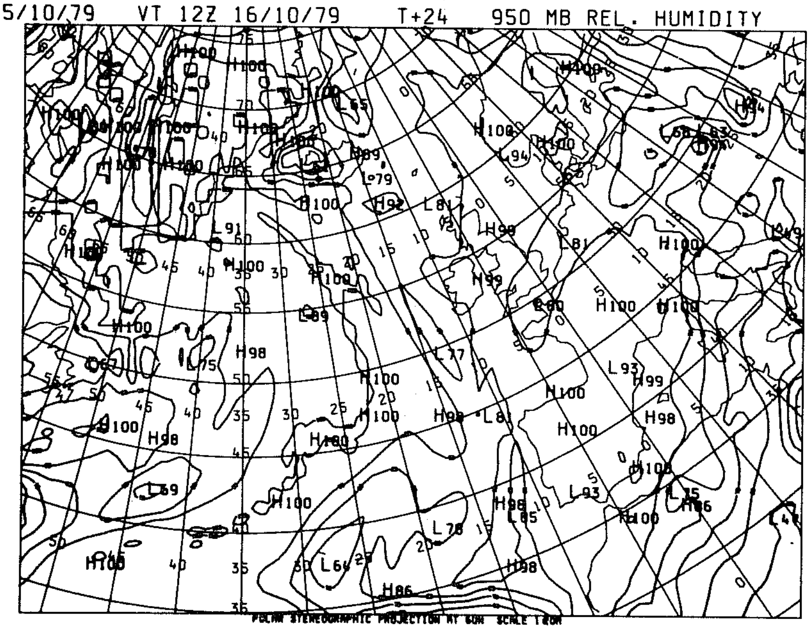


CHART 16
M22CCTS2

Fig. 5

DT 12Z 15/10/79 VT 12Z 16/10/79 T+24 950 MB REL. HUMIDITY (20% INT) UPDATE

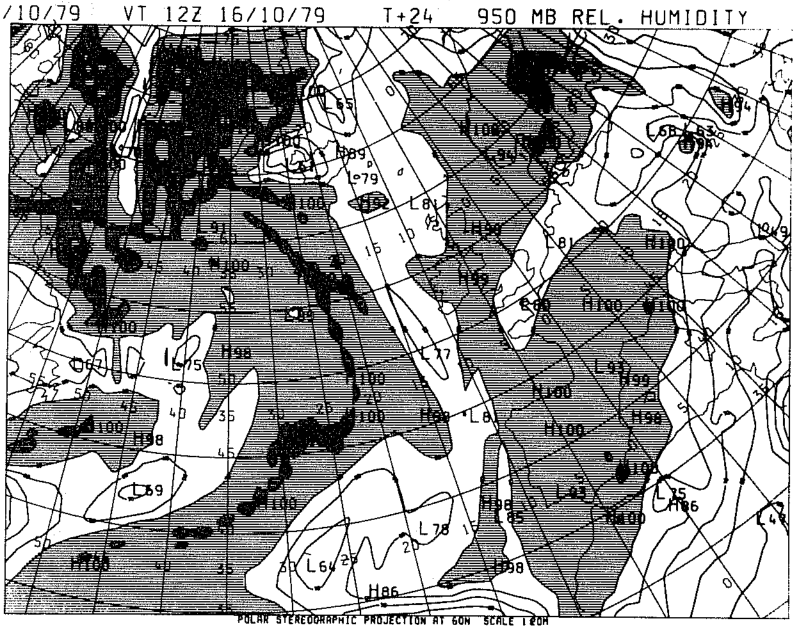


CHART 16
M22CCTS3

Fig. 6

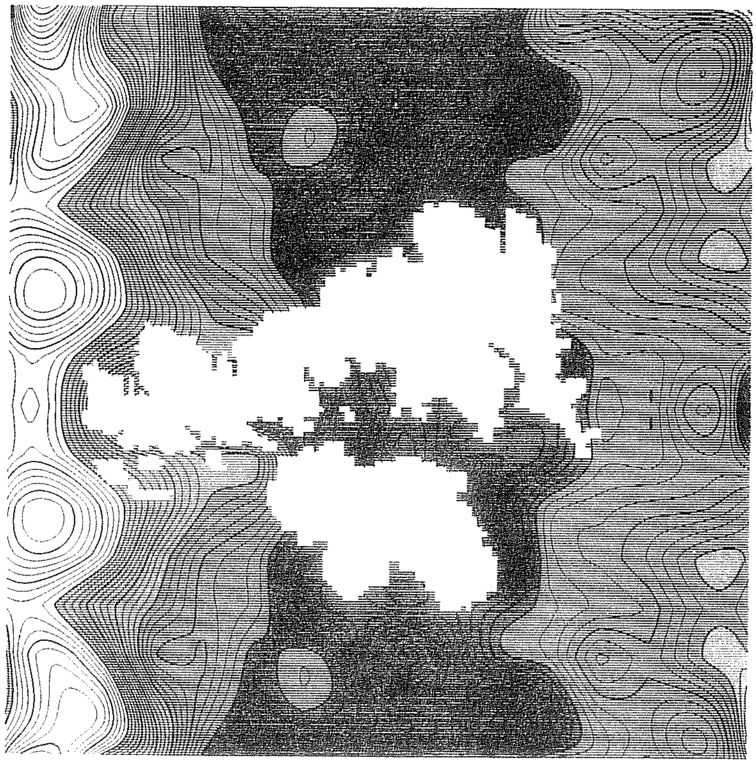

Fig. 7

Fig. 8

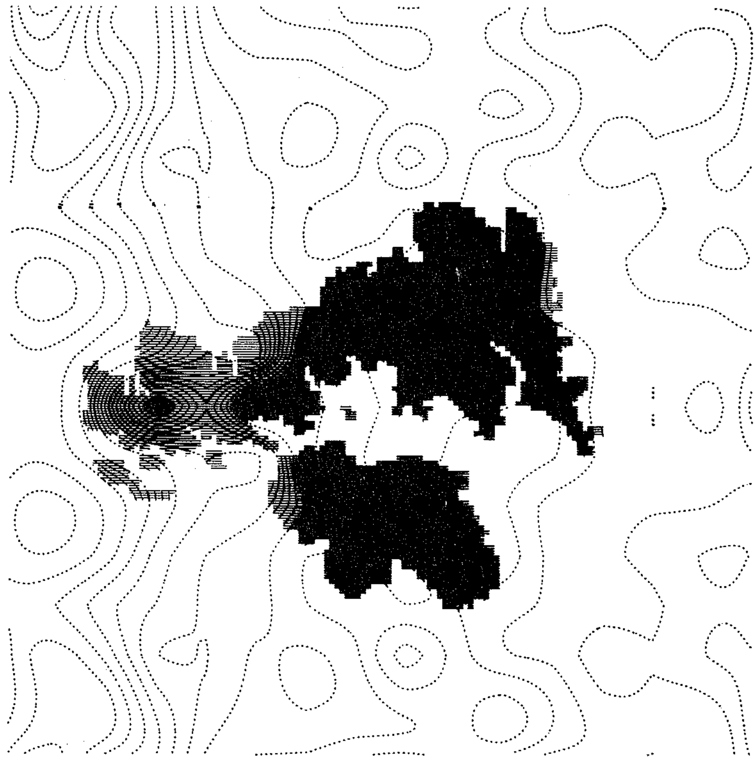

Fig. 10

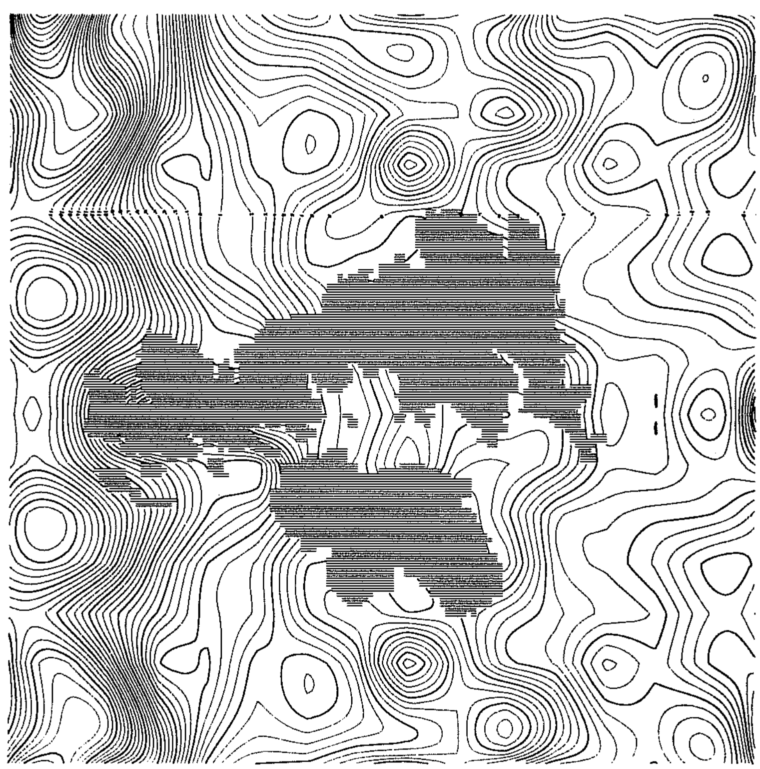

Fig. 9